



Failure Analysis of a Cracked UH-1 Tailboom Former, P/N 205-030-807-97

by Scott Grendahl, Benjamin Hardisky, and Russell Yocum

ARL-TR-3828

June 2006

prepared by

**Scott Grendahl
U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Aberdeen Proving Ground, MD 21005**

**Benjamin Hardisky and Russell Yocum
U.S. Army Aberdeen Test Center
Physical Test Unit
Aberdeen Proving Ground, MD 21005**

for

**U.S. Army Aviation and Missile Command
Huntsville, AL 35899**

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5069

ARL-TR-3828**June 2006**

Failure Analysis of a Cracked UH-1 Tailboom Former, P/N 205-030-807-97

prepared by

Scott Grendahl

**U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Aberdeen Proving Ground, MD 21005**

**Benjamin Hardisky and Russell Yocum
U.S. Army Aberdeen Test Center
Physical Test Unit
Aberdeen Proving Ground, MD 21005**

for

**U.S. Army Aviation and Missile Command
Huntsville, AL 35899**

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) June 2006		2. REPORT TYPE Final		3. DATES COVERED (From - To) 1 January 2005–31 August 2005	
4. TITLE AND SUBTITLE Failure Analysis of a Cracked UH-1 Tailboom Former, P/N 205-030-807-97				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Scott Grendahl, Benjamin Hardisky, * and Russell Yocum *				5d. PROJECT NUMBER M042-489Y31	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-WM-MC Aberdeen Proving Ground, MD 21005-5069				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-3828	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Aviation and Missile Command Huntsville, AL 35899				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES *U.S. Army Aberdeen Test Center, Physical Test Unit, Aberdeen Proving Ground, MD 21005-5069					
14. ABSTRACT The U.S. Army Aviation and Missile Command sent the U.S. Army Research Laboratory Weapons and Materials Research Directorate a UH-1 tailboom former (P/N 201030-807-97) from the U.S. Army Kwajalein Atoll Facility (USAKA) in the Marshall Islands for investigation. The component was being investigated due to the presence of cracks observed near bolt hole locations on the part. This component was quality deficient report exhibit number M24H90327. The material utilized to manufacture the former was specified to be clad 2024-T4 aluminum alloy sheet in accordance with QQ-A-362. It was superseded by QQ-A-250/5B, which was subsequently cancelled, and superseded by the current specification for clad 2024-T4 aluminum sheet, SAE-AMS-QQ-A-250-5. The part was characterized through nondestructive inspection, chemical analysis, optical microscopy, scanning electron microscopy, and mechanical testing.					
15. SUBJECT TERMS failure analysis, 9310 steel, fatigue, helicopter gear					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 30	19a. NAME OF RESPONSIBLE PERSON Scott Grendahl
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (Include area code) 410-306-0819

Contents

List of Figures	iv
List of Tables	iv
1. Introduction	1
2. Fluorescent Penetrant Inspection and Eddy Current Testing	2
3. Visual Inspection and Light Optical Microscopy	3
4. Scanning Electron Microscopy (SEM)	6
5. Metallography	12
6. Chemical Analysis	15
7. Hardness and Conductivity Testing	15
8. Coating System	15
9. Failure Scenario	16
10. Conclusions	19
Distribution List	20

List of Figures

Figure 1. As-received component UH-1 tailboom former.....	1
Figure 2. Fluorescent indication of the crack on side A.	2
Figure 3. Fluorescent indication of the crack on side B.	3
Figure 4. One half of the fracture surface of the crack on side A.....	4
Figure 5. Fractograph of one half of the fracture surface.	4
Figure 6. Fractograph of the corrosion initiation site on side A.	5
Figure 7. Fractograph of the corrosion initiation site on side A at 45°.....	5
Figure 8. Fractograph of the corrosion initiation site on side B.	6
Figure 9. Fractograph of the corrosion initiation site on side B at 45°.....	7
Figure 10. Fractograph of the origin near the center of the crack.....	7
Figure 11. SEM fractograph of the whole crack on one fracture half.	8
Figure 12. Transgranular fatigue to ductile overload transition zone.....	8
Figure 13. Fractograph of the origin area on side A.	9
Figure 14. Fractograph of the origin area at 45° on side A.	9
Figure 15. Higher magnification image of the large corrosion pit on side A.	10
Figure 16. Fractograph of the origin area on side B.	10
Figure 17. Fractograph of the origin area at 45° on side B.....	11
Figure 18. SEM micrograph of the center fatigue initiation site.	11
Figure 19. SEM micrograph of the center fatigue initiation site at 45°.....	12
Figure 20. Longitudinal cross section showing the cladding of the 2024-T4 alloy.....	13
Figure 21. Transverse cross section showing the cladding of the 2024-T4 alloy.....	13
Figure 22. Longitudinal microstructure of the 2024-T4 alloy.	14
Figure 23. Transverse microstructure of the 2024-T4 alloy.	14
Figure 24. Former compared with a golden yellow chromate conversion coated component.	17
Figure 25. Exterior surface of the tailboom former coated with MIL-P-23377.	17
Figure 26. Corrosion pitting band near edge of crevice compression line.	18
Figure 27. Pits adjacent to the edge of the fracture.....	18
Figure 28. Pitting and corrosion product along the edge of compression line.	19

List of Tables

Table 1. Chemical composition of the tailboom former, weight percent.	15
--	----

INTENTIONALLY LEFT BLANK.

1. Introduction

The U.S. Army Aviation and Missile Command sent the U.S. Army Research Laboratory Weapons and Material Research Directorate a UH-1 tailboom former (P/N 201030-807-97) from the U.S. Army Kwajalein Atoll facility (USAKA) in the Marshall Islands for investigation. The component was being investigated due to the presence of cracks observed near bolt hole locations on the part. This component was quality deficiency report exhibit number M24H90327. The material utilized to manufacture the former was specified to be clad 2024-T4 aluminum alloy sheet IAW QQ-A-362. QQ-A-362 is a very old cancelled specification. No copies of that specification could be recovered. It was superseded by QQ-A-250/5B, which was subsequently cancelled, and superseded by the current specification for clad 2024-T4 aluminum sheet, SAE-AMS-QQ-A-250-5. The part was characterized through nondestructive inspection, chemical analysis, optical microscopy, scanning electron microscopy, and mechanical testing. Figure 1 depicts the as-received tailboom former from USAKA.

The objective of this work was to determine the root cause of the cracking observed on the UH-1 tailboom former (P/N 205-030-807-97).

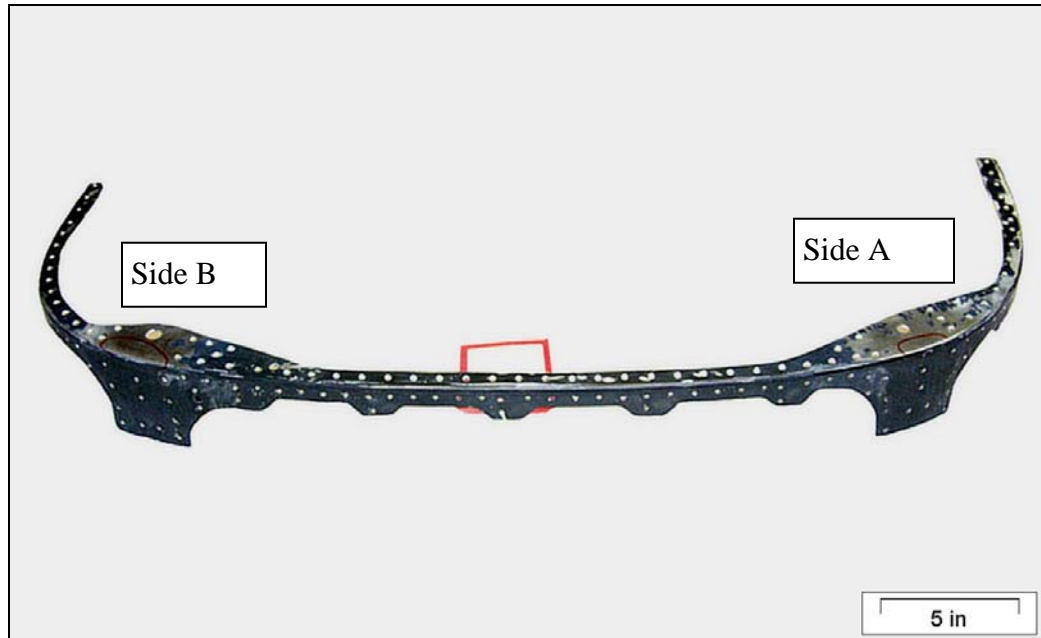


Figure 1. As-received component UH-1 tailboom former.

2. Fluorescent Penetrant Inspection and Eddy Current Testing

The penetrant materials included ZL-37 post emulsifiable hydrophilic penetrant (sensitivity level 4), ZR-10B remover (slow acting), and ZP-9F developer. This inspection was performed in accordance with MIL-STD-271F(SH),¹ MIL-STD-6866B,² and ASTM E-165.³ Penetrant inspection dwell times were doubled, the emulsifier times were reduced by 25%, and the developer dwell time was increased to 12 min to increase the possibility of detecting extremely tight flaws. The eddy current inspection utilized an Automation Industries 6300 eddy current unit, a 500-kHz shielded absolute pancake probe, 1/8-in diameter pencil, 500-kHz shielded absolute pancake probe 1/4-in diameter (spring loaded), and a Zetek aluminum electric discharge machine block.

A 2.69-cm indication was noted on side A of the as-received image in figure 1. The crack can be observed at a higher magnification in figure 2. The ECI revealed the approximate depth ranged from 0.020 to 0.04 in and the width ranged from 0.003 to 0.005 in. No penetrant bleed through was noted on the inside face of the former (paint was not removed from the inside, concave surface).



Figure 2. Fluorescent indication of the crack on side A.

¹MIL-STD-271F(SH). *Requirements for Nondestructive Testing Methods* **1986**.

²MIL-STD-6866B. *Inspection, Liquid Penetrant* **1985**.

³ASTM E-165. *Standard Test Method for Liquid Penetrant Examination. Annu. Book ASTM Stand.* **2002**.

An extremely faint 3.50-cm indication was noted on side B of the as-received image in figure 1. The crack can be observed at a higher magnification in figure 3. The ECI revealed that the depth ranged from 0.020 to 0.040 in and the maximum width was 0.005 in. The eddy current measurements were approximate, as the proximity to the edge made the inspection difficult. No penetrant bleed through was noted on the inside face of the former (paint was not removed from inside concave surface).



Figure 3. Fluorescent indication of the crack on side B.

3. Visual Inspection and Light Optical Microscopy

The tailboom former was inspected visually and with light optical microscopy. Two cracks were observed, one near the hole on side A, and the other near the hole on side B. The proximity of the crack to the hole was ~0.75 inches in each case. The crack on side A was opened mechanically for fractographic examination. The opened crack is shown in figure 4, with the origins labeled in red. One half of the fracture surface is shown in figure 5. This crack had three distinct origins. Two of the origins were corrosion pits initiating on the concave side. The corrosion initiation site on side A can be observed in figures 6 and 7 (figure 7 depicts a 45° tilt). There were three small corrosion pits in this area, so the initiation site was actually a region rather than a specific point. The largest of the corrosion pits appeared to be ~0.005 in deep. The

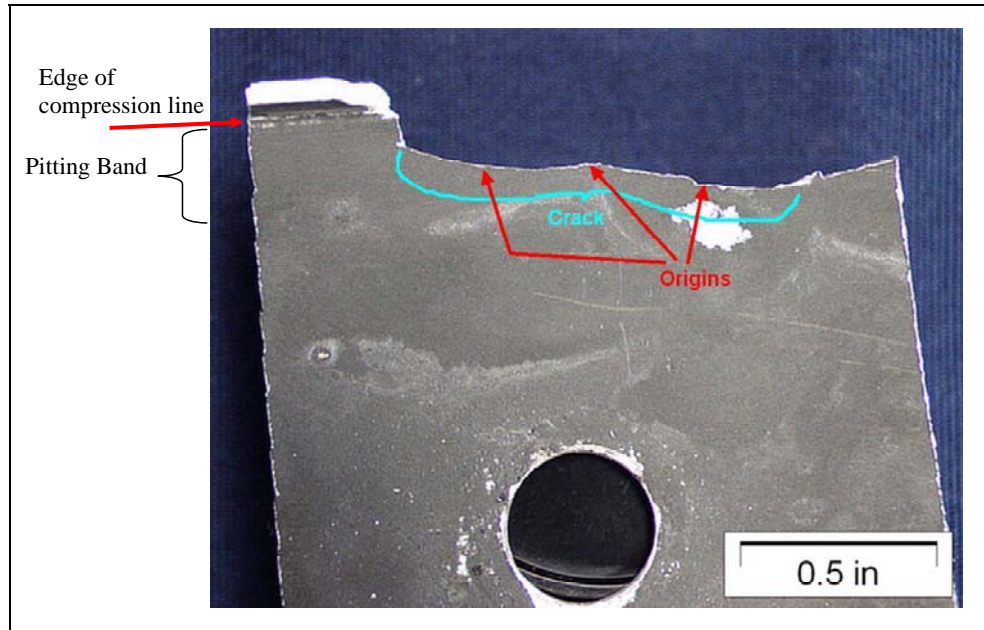


Figure 4. One half of the fracture surface of the crack on side A.

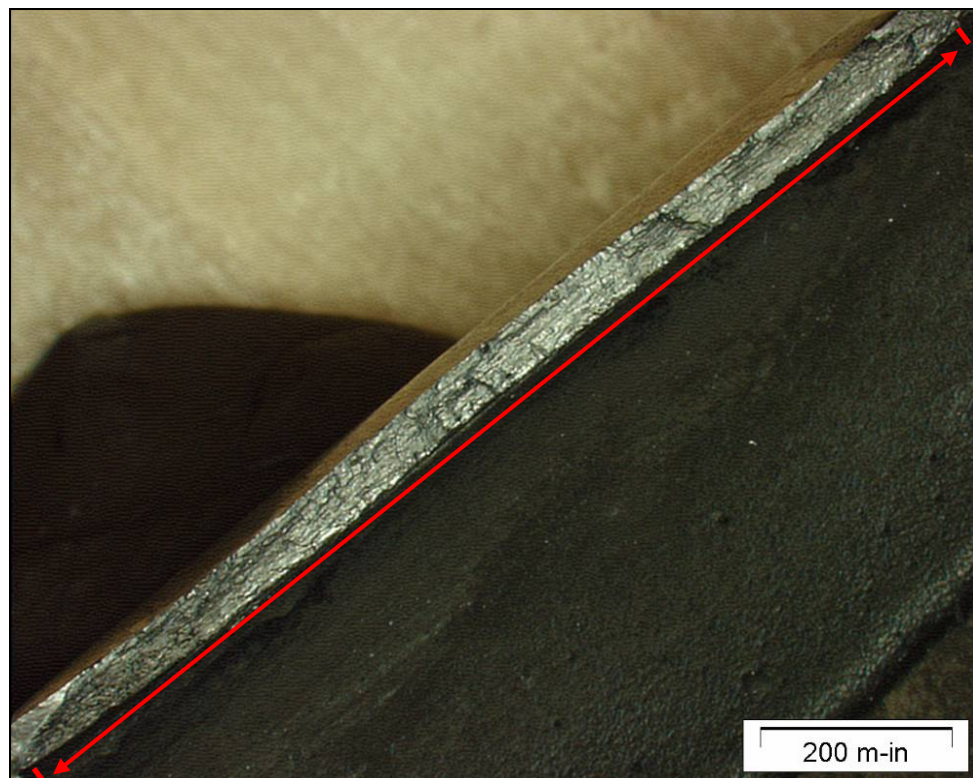


Figure 5. Fractograph of one half of the fracture surface.

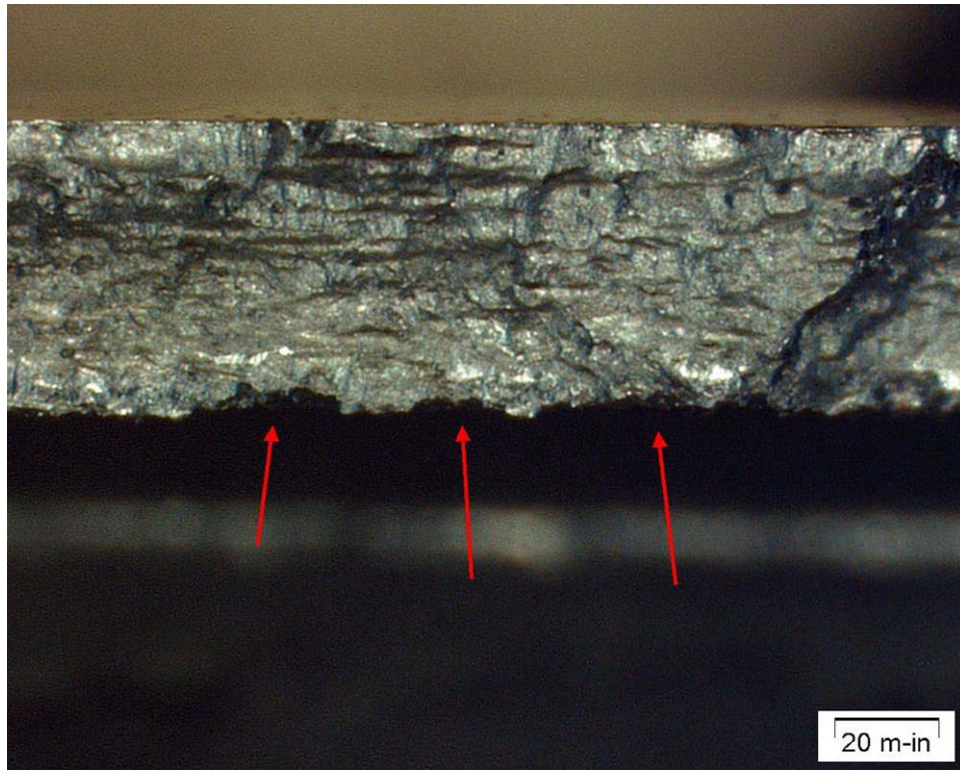


Figure 6. Fractograph of the corrosion initiation site on side A.

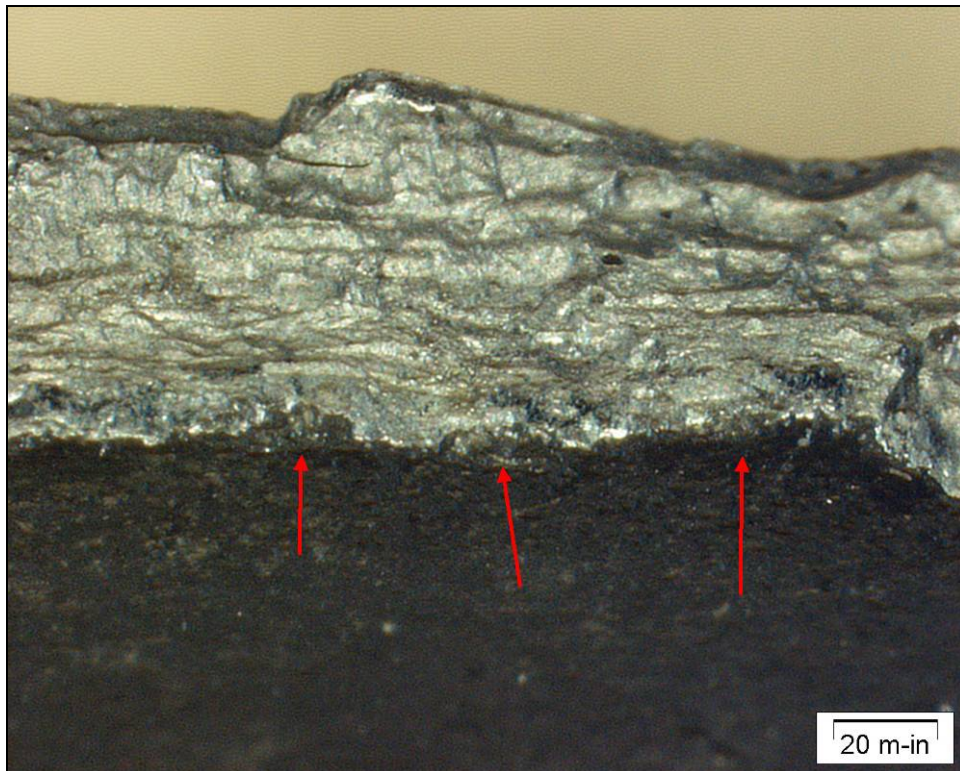


Figure 7. Fractograph of the corrosion initiation site on side A at 45°.

corrosion initiation site on side B can be observed in figures 8 and 9 (figure 9 depicts a 45° tilt). Crack arrest lines (beach marks) and chevron patterns were observable on the fracture surface near these origins. The third origin was fatigue initiated at a surface imperfection unrelated to corrosion, but also on the concave side of the component. This initiation site can be observed in figure 10. The crack progression spread out symmetrically from these three points to form a final crack length of 1.25 in, as observed in figure 5. It was apparent that the cracks joined together and propagated entirely through the 0.050-in thickness of the tailboom former.

4. Scanning Electron Microscopy (SEM)

SEM, utilizing a JEOL-JSM 6460-LV, was performed to investigate the fracture surfaces in greater detail. The fracture surface of the opened crack is depicted in the electron fractograph in figure 11. The total crack length measured 1.25 in. At closer inspection, evidence of cyclic fatigue crack propagation was present (figure 12). Fatigue progression lines can easily be observed (this is the transition region at the end of the crack between transgranular fracture and ductile overload). The fracture morphology was transgranular throughout the cracked region. The origin area on side A is depicted in figure 13 and at 45° in figure 14. A higher magnification image of the large corrosion pit on side A is shown in figure 15. The origin area on side B is depicted in figure 16 and at 45° in figure 17. The third initiation site can be observed in figures 18 and 19. All the origins were on the concave side of the part.

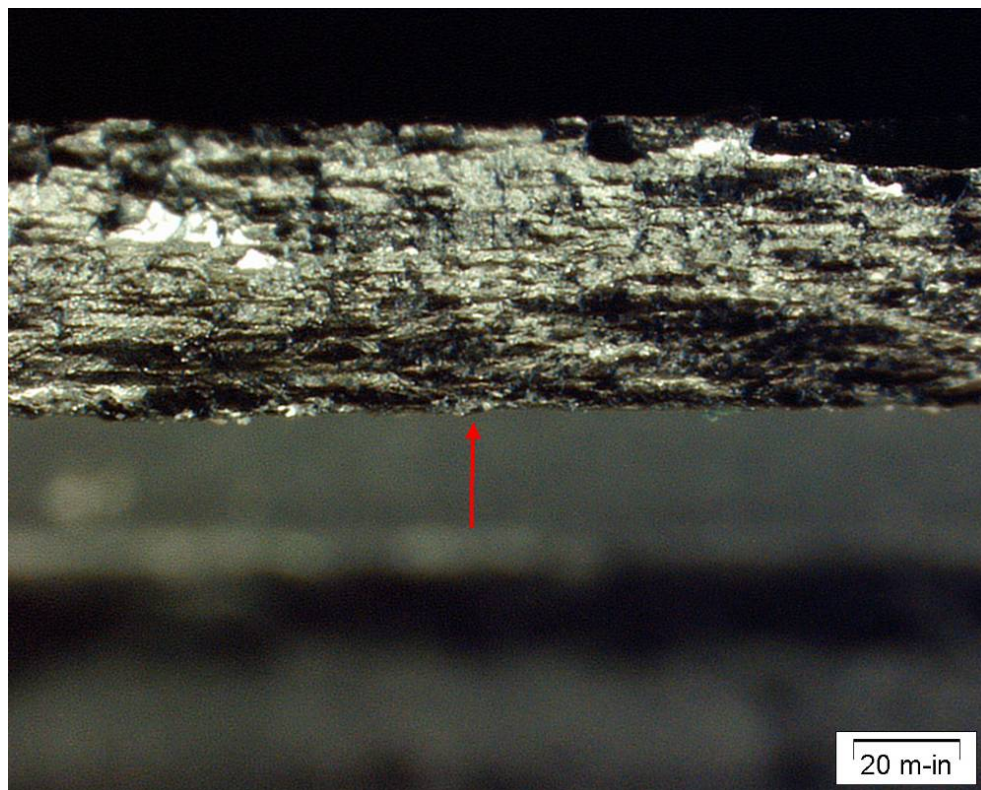


Figure 8. Fractograph of the corrosion initiation site on side B.

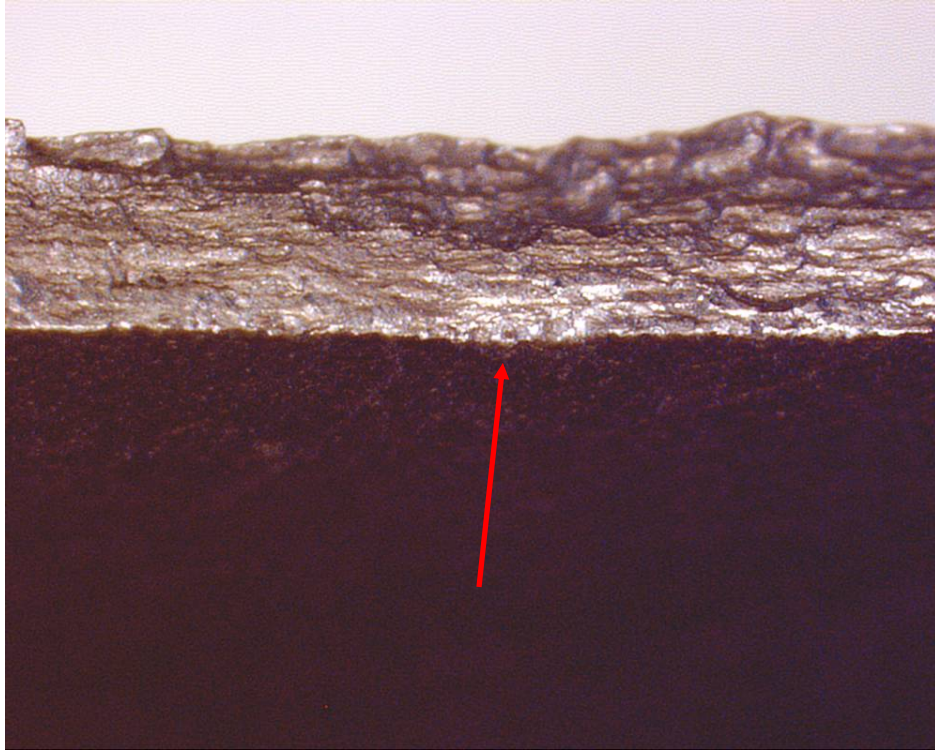


Figure 9. Fractograph of the corrosion initiation site on side B at 45°.

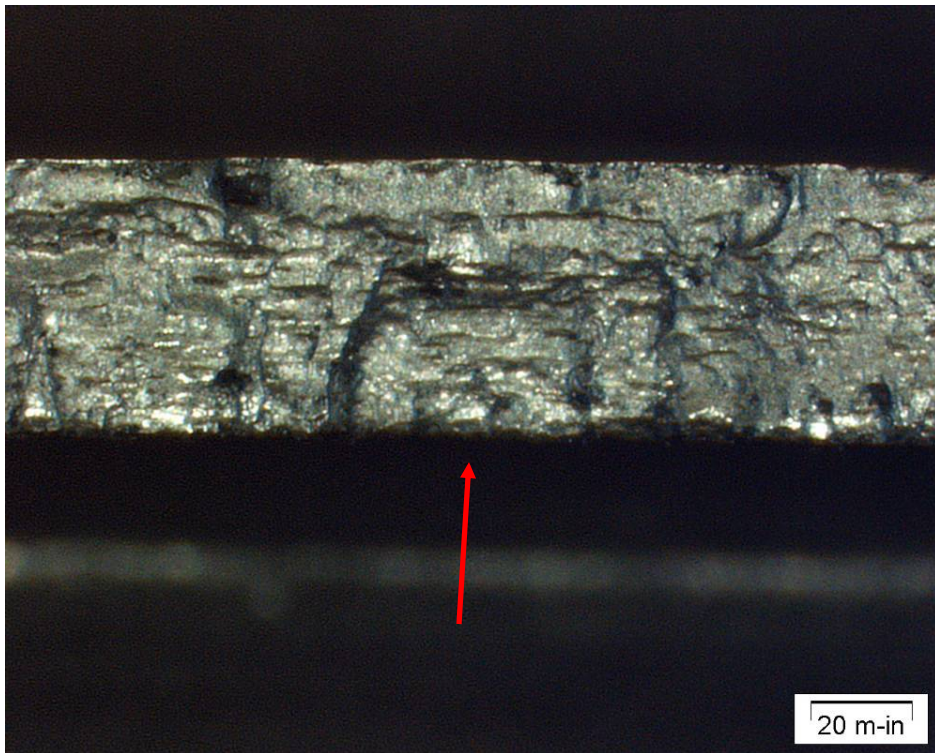


Figure 10. Fractograph of the origin near the center of the crack.

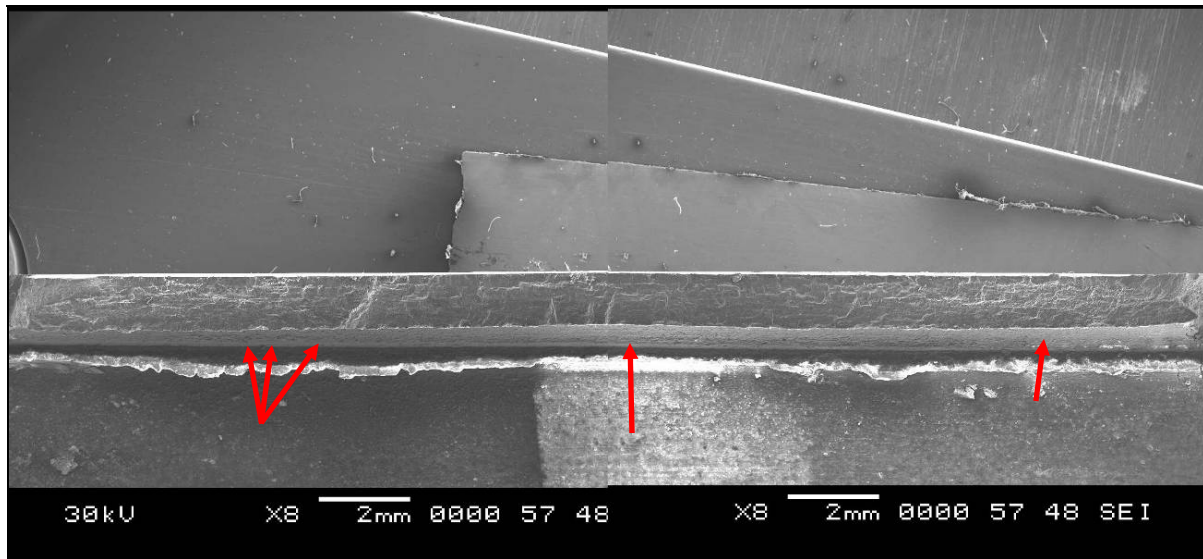


Figure 11. SEM fractograph of the whole crack on one fracture half.

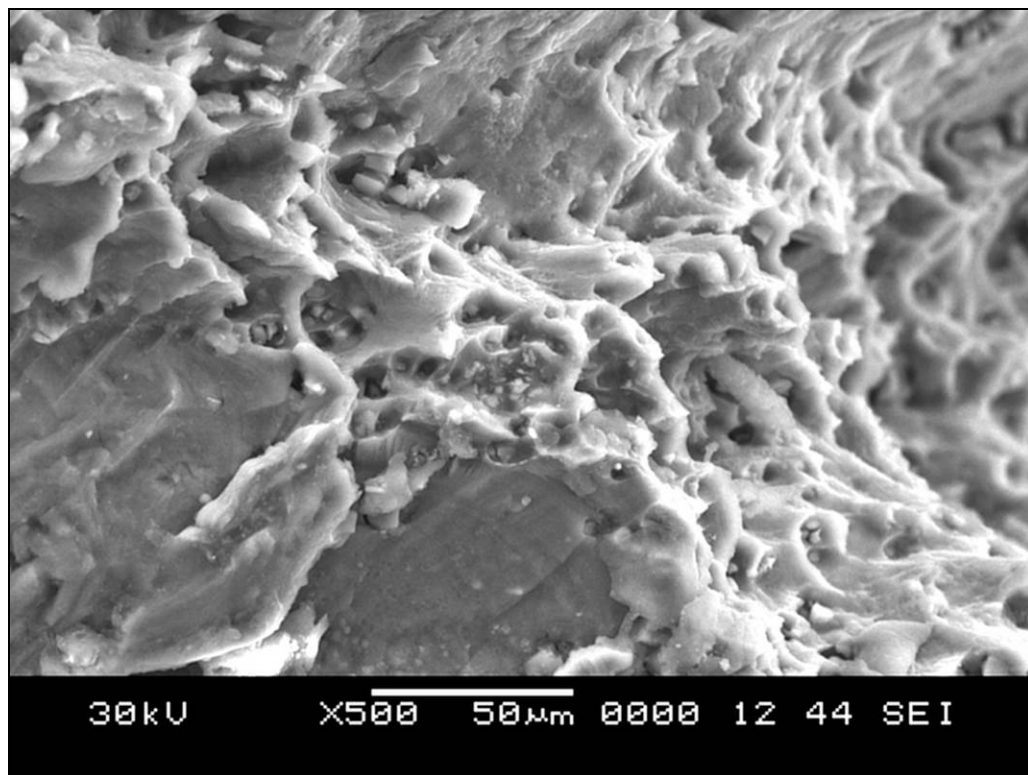


Figure 12. Transgranular fatigue to ductile overload transition zone.

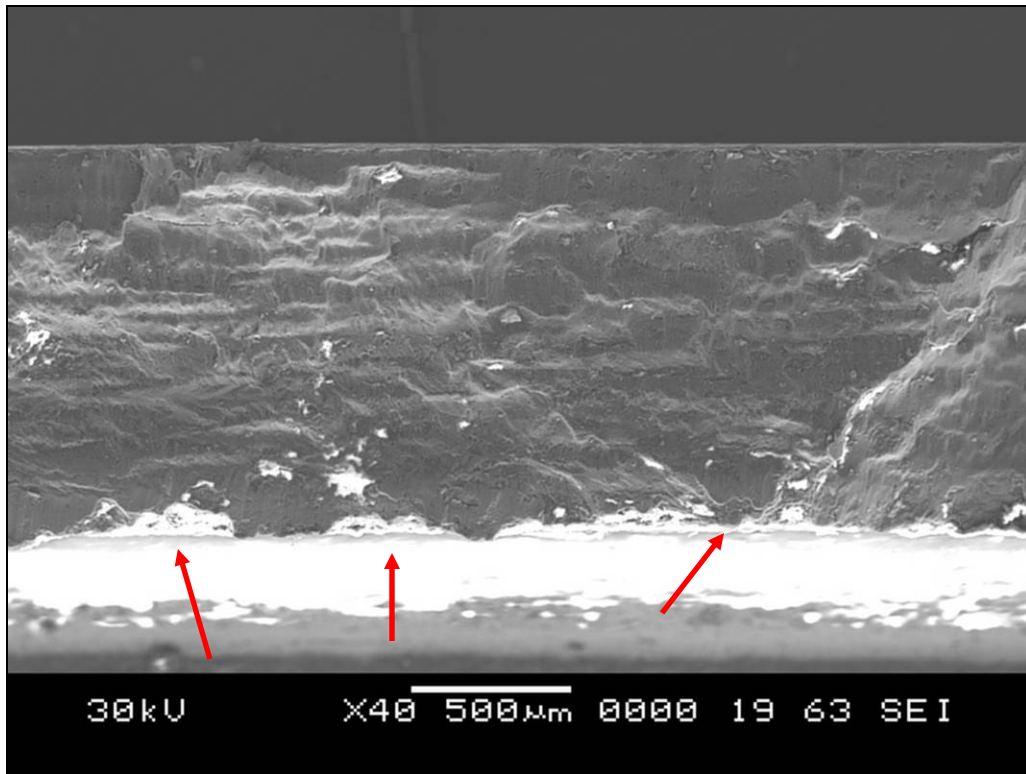


Figure 13. Fractograph of the origin area on side A.

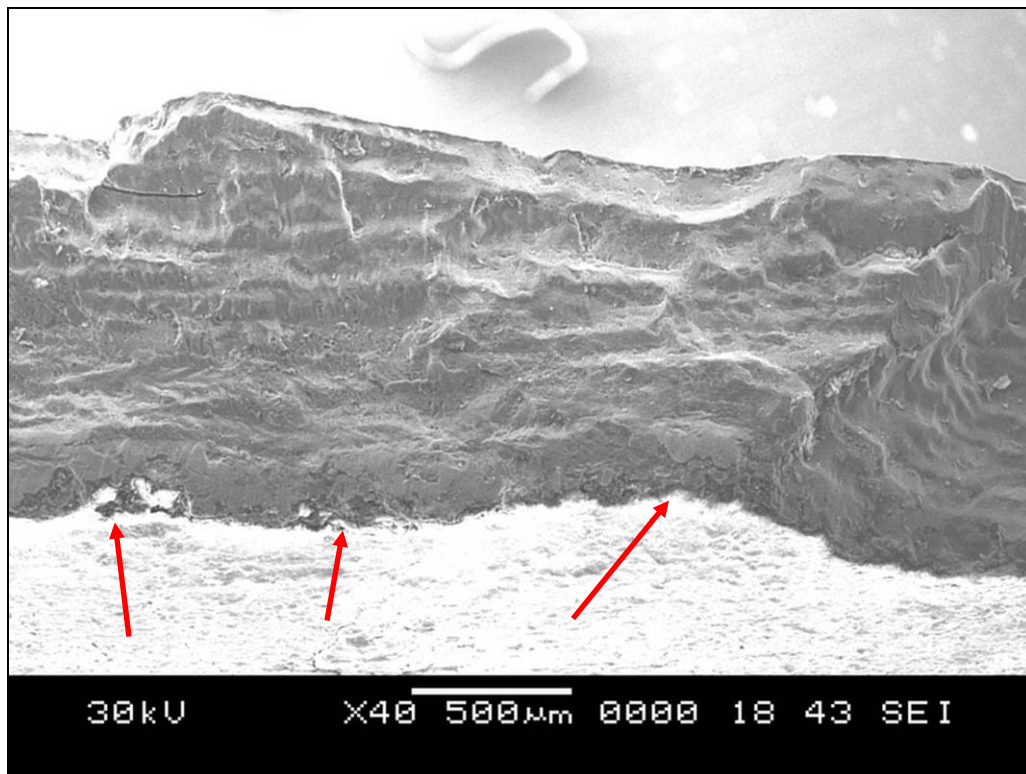


Figure 14. Fractograph of the origin area at 45° on side A.

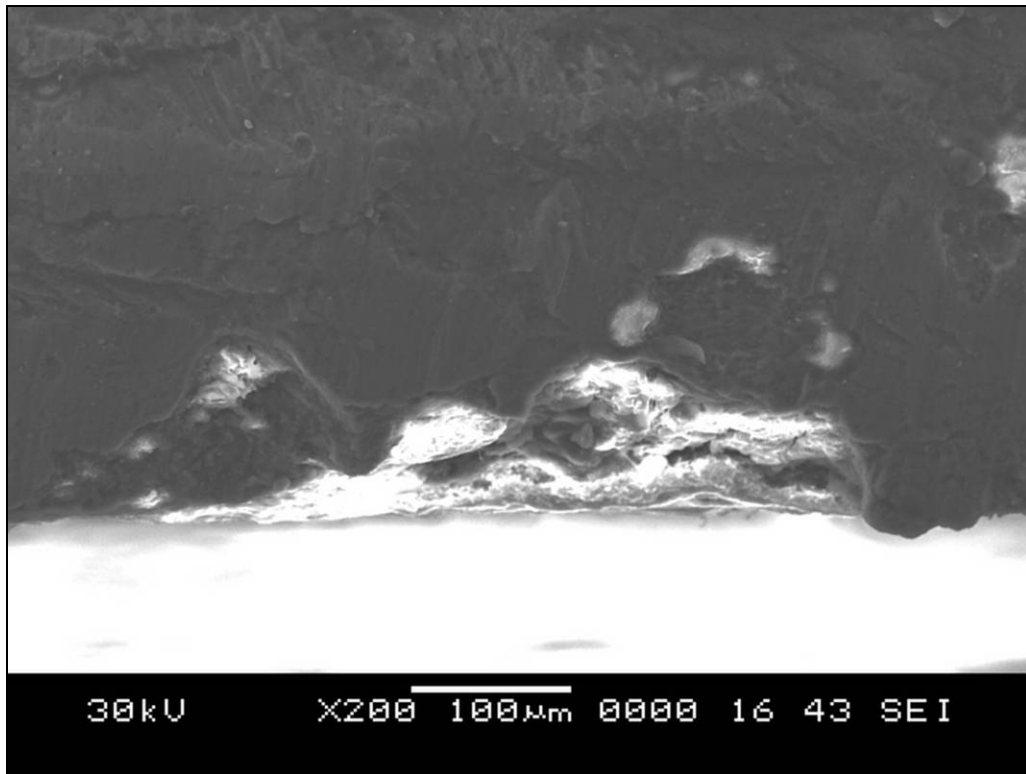


Figure 15. Higher magnification image of the large corrosion pit on side A.

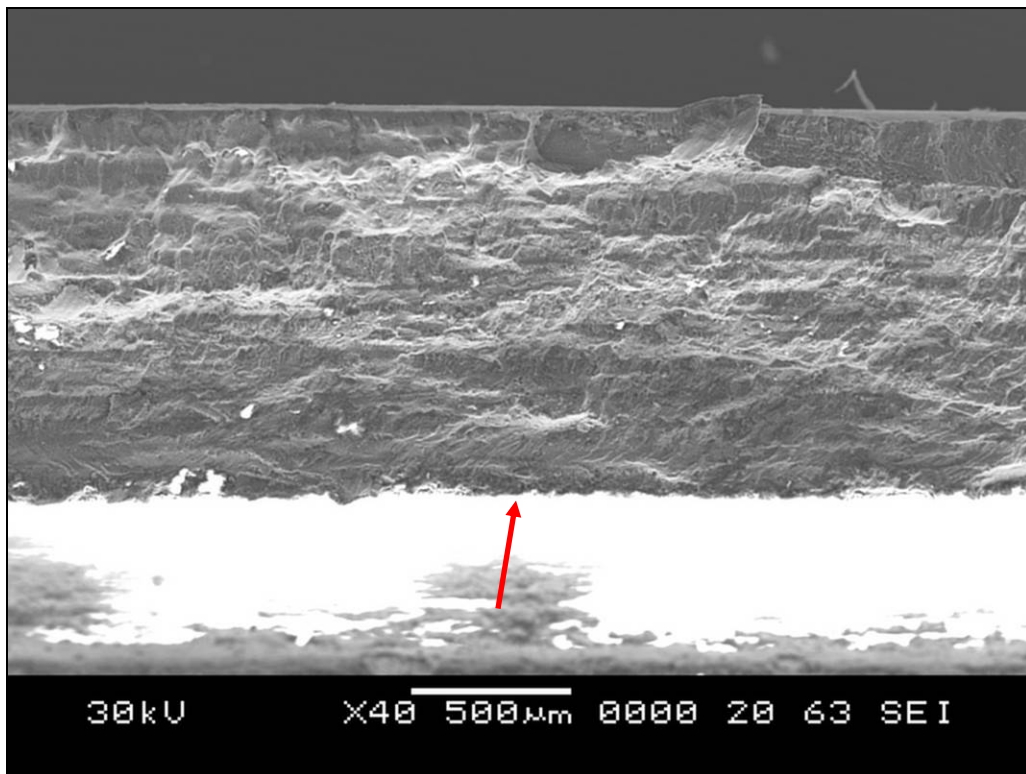


Figure 16. Fractograph of the origin area on side B.

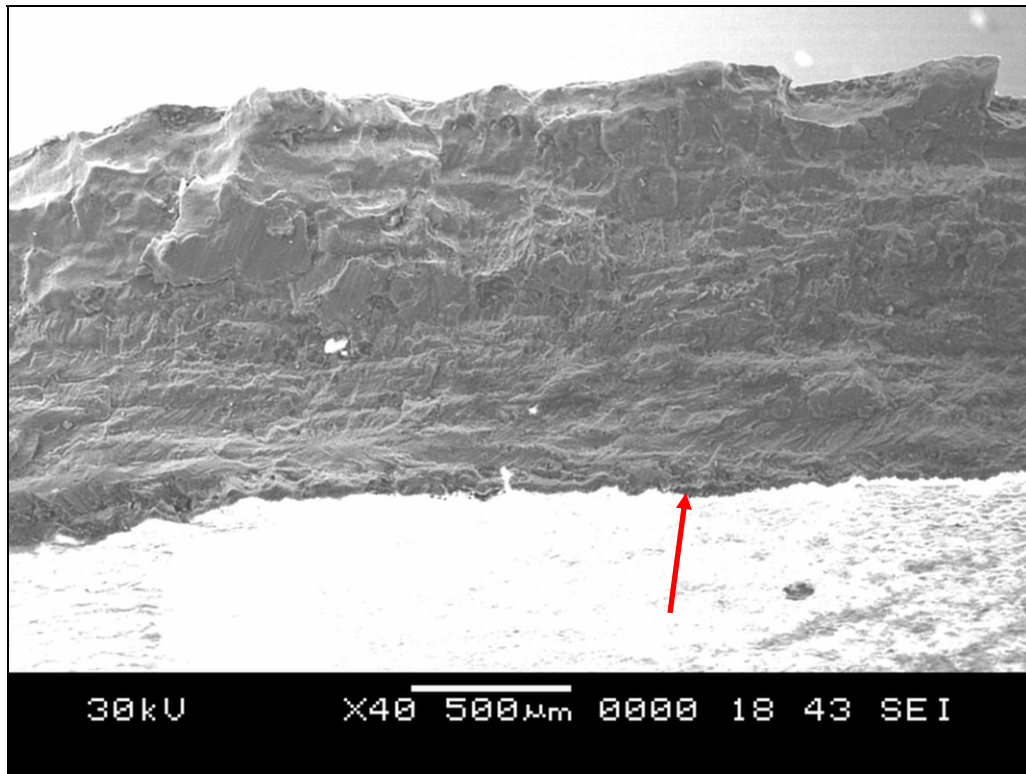


Figure 17. Fractograph of the origin area at 45° on side B.

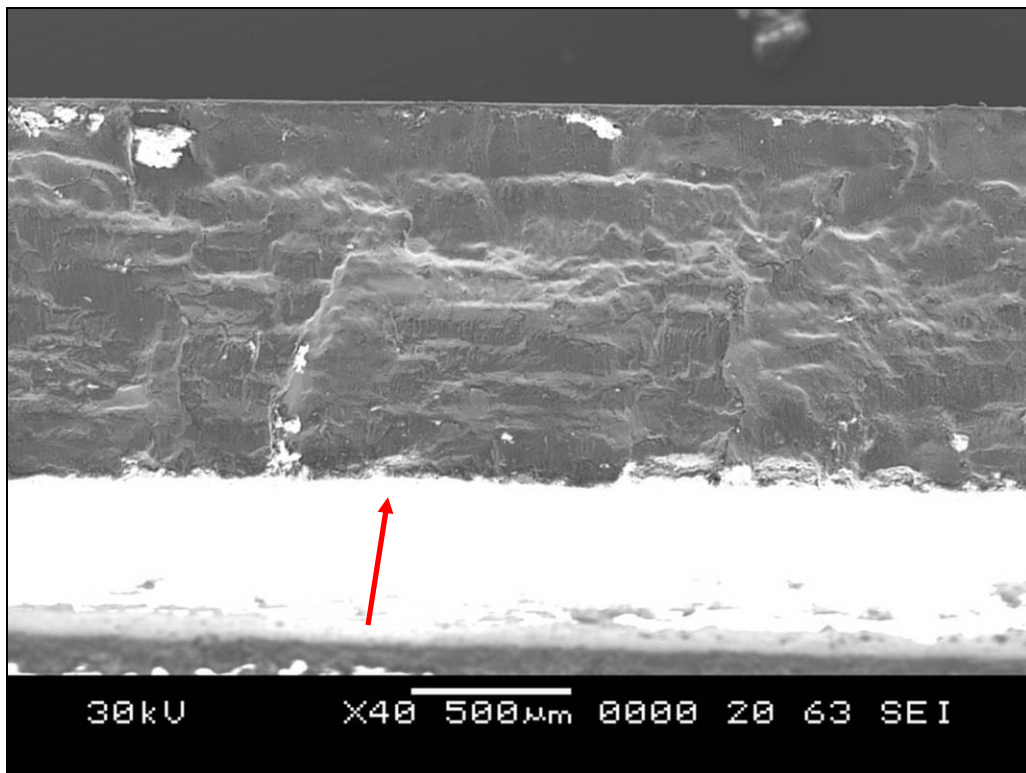


Figure 18. SEM micrograph of the center fatigue initiation site.

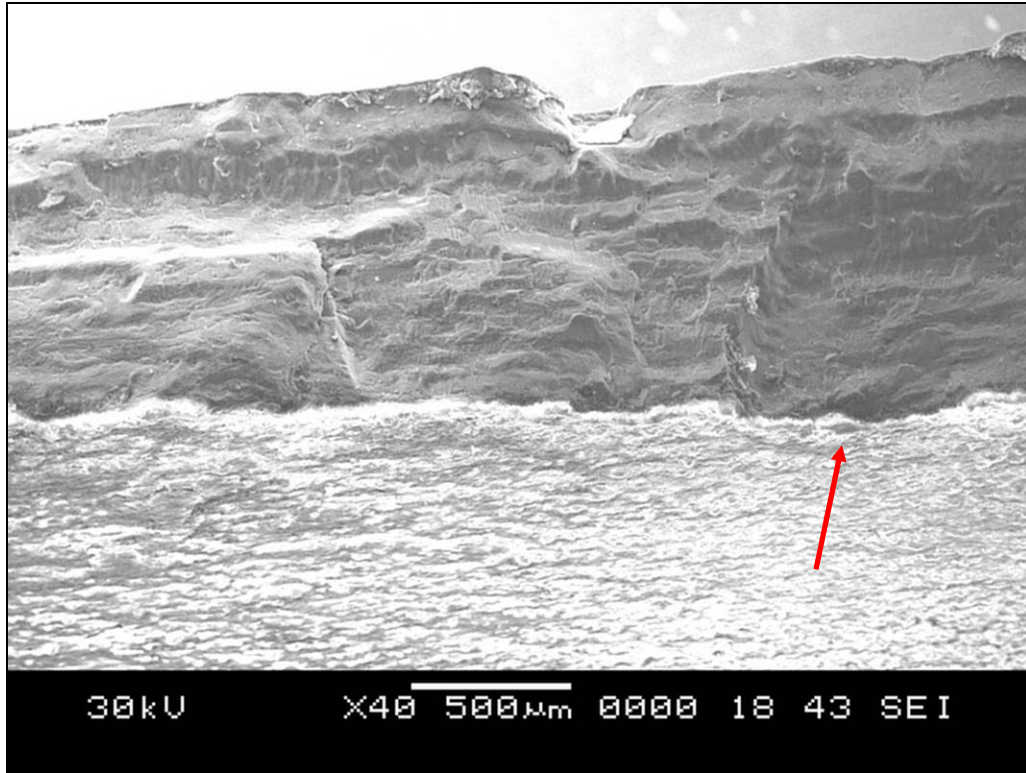


Figure 19. SEM micrograph of the center fatigue initiation site at 45°.

5. Metallography

Longitudinal and transverse (to the sheet rolling direction) cross sections were metallographically prepared. The sections were ground and polished through 0.025- μm noncolloidal silica. Subsequently, the specimen was etched with Keller's reagent. The microstructure of the tailboom former material was found to be consistent with clad 2024-T4 aluminum alloy. The cladding can be observed in the longitudinal and transverse direction in figures 20 and 21. The precipitates were determined to be CuMgAl_2 , $\text{Cu}_2\text{MnAl}_{20}$, and Cu_2FeAl_7 . The smaller precipitates formed during the annealing process, while the larger precipitates were undissolved from the solutionizing treatment. No abnormalities were observed. Representative photos of both the longitudinal and transverse cross sections are observable in figures 22 and 23, respectively.

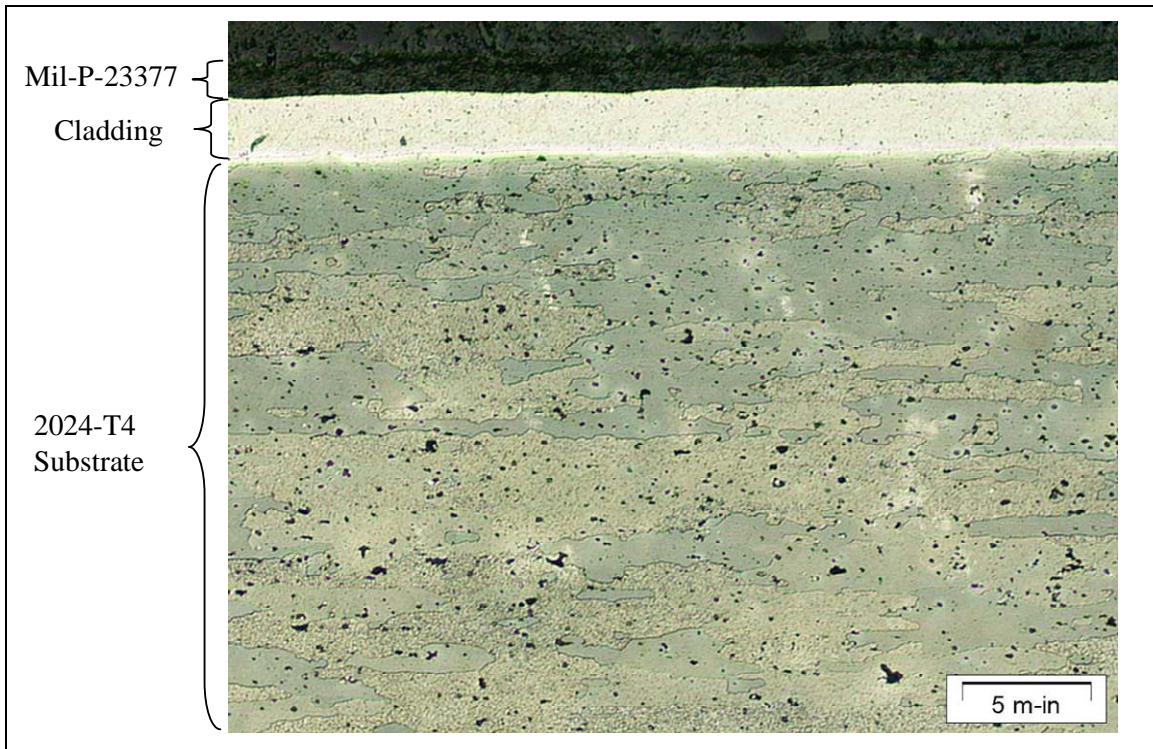


Figure 20. Longitudinal cross section showing the cladding of the 2024-T4 alloy.

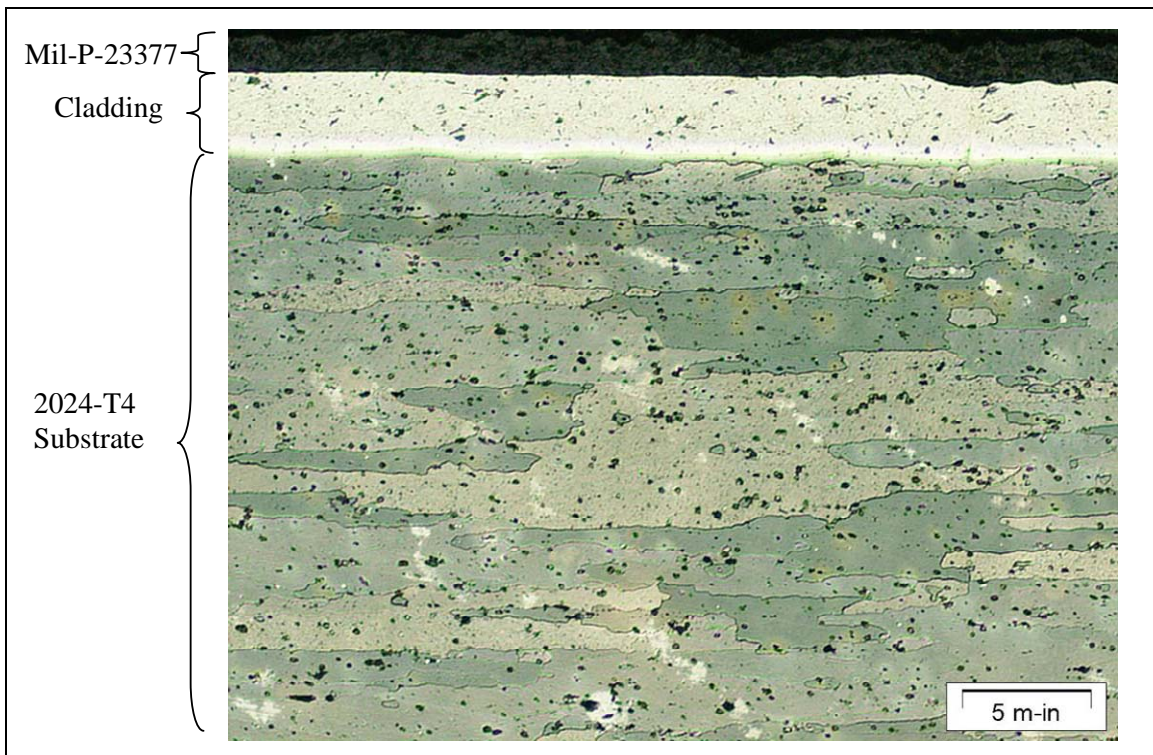


Figure 21. Transverse cross section showing the cladding of the 2024-T4 alloy.

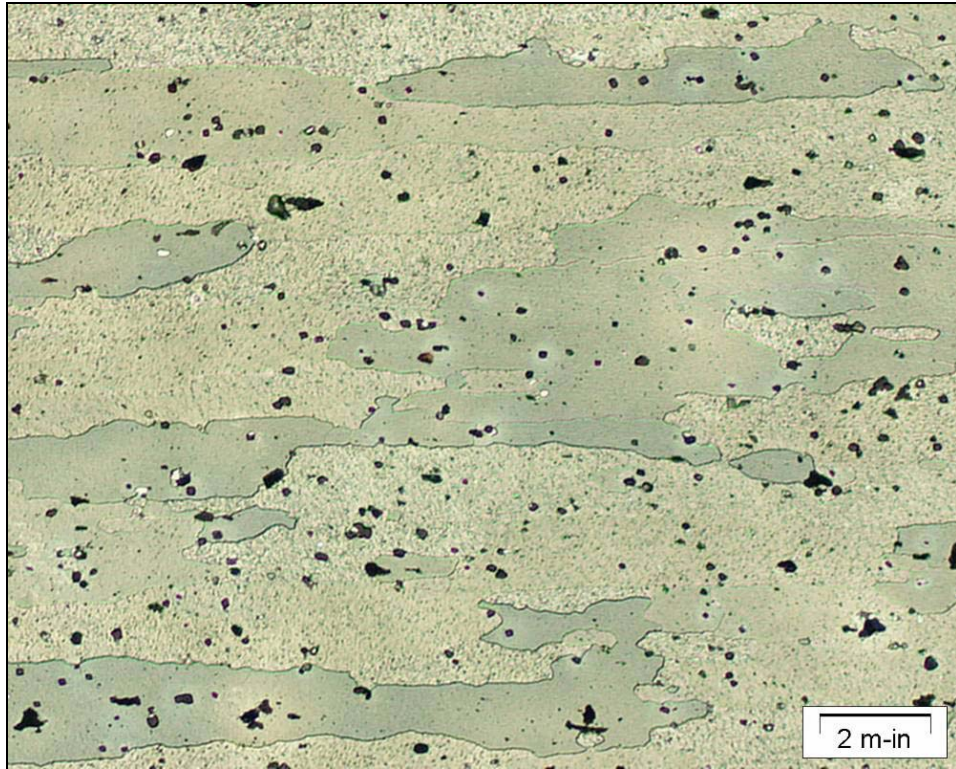


Figure 22. Longitudinal microstructure of the 2024-T4 alloy.

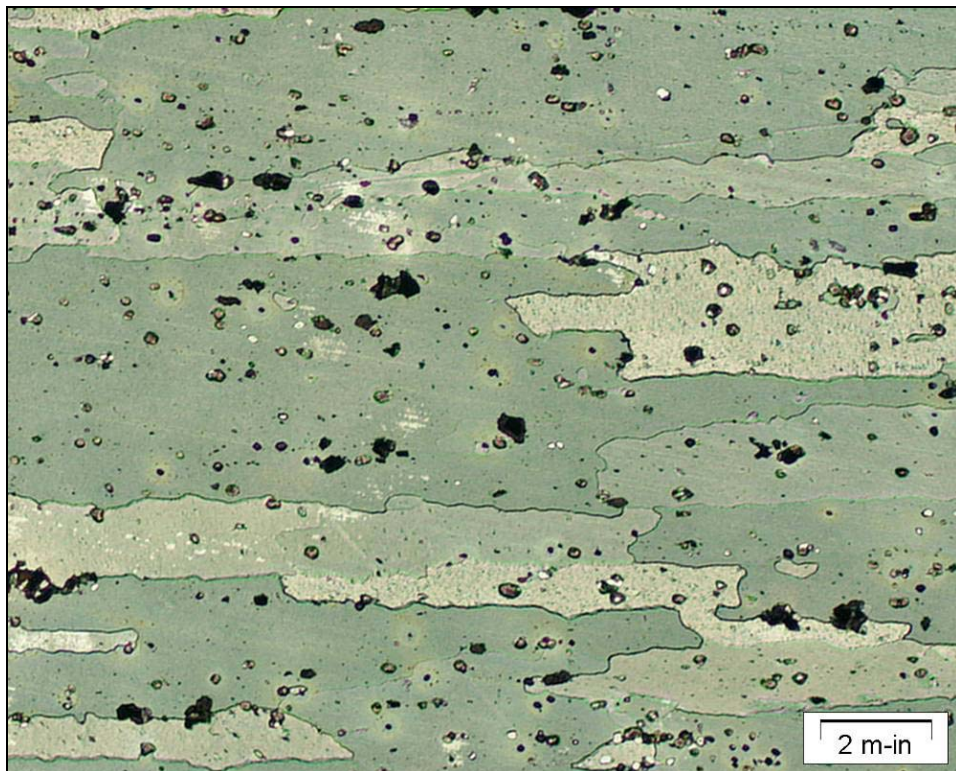


Figure 23. Transverse microstructure of the 2024-T4 alloy.

6. Chemical Analysis

The chemical composition of the tailboom former was analyzed with direct current plasma emission spectroscopy (DC plasma). The sample was sectioned from an area adjacent to the bolt hole where the cracks were located. The results are listed, along with the chemical composition requirements as required by the engineering drawing in table 1. The chemical constituency of the component compared favorably with the specified requirements in SAE-AMS-QQ-A-250-5.

Table 1. Chemical composition of the tailboom former, weight percent.

Element	Former (%)	SAE-AMS-QQ-A-250-5 (%)
Iron	0.24	0.50 max
Manganese	0.49	0.30–0.90
Silicon	0.090	0.50 max
Copper	4.34	3.8–4.9
Zinc	0.089	0.25 max
Magnesium	1.41	1.20–1.80
Chromium	0.016	0.10 max
Titanium	0.025	0.15 max
Gallium	0.011	0.05 max
Vanadium	0.030	0.05 max
Nickel	0.012	0.05 max
Aluminum	Remainder	Remainder

7. Hardness and Conductivity Testing

Hardness and conductivity measurements were made near the cracked areas on the outside surface of the tailboom former. The hardness of the component measured 45.0 HRA, (measured 153 HV) and the conductivity measured 31.0% IACS. These values compared favorably with typical clad aluminum 2024-T4 alloy.

8. Coating System

Since the apparent cause of failure of this component was fatigue initiated at corrosion pits, the coating system itself was investigated. The coating system for the tailboom former was required to be chromate conversion coating (golden yellow to brown) with one coat of MIL-P-23377, type II primer (applied per MIL-C-53072) in accordance with the Spares TDP 205-030-807 and Bell Helicopter Specification BPS 4182. The MIL-P-23377 was chemically removed so the chromate

conversion coating could be visually inspected. There was no visible golden yellow to brown chromate conversion under the primer. Two important notes accompany this fact. The first is contingent upon the age of the component; the golden yellow to brown color can fade over time as it is meant to be sacrificial. The second is simply that a clear coat chromate conversion treatment (not in accordance with the specification) would not be visible. So the case exists that either the chromate coating has degraded over time or it was never applied correctly when the part was manufactured. The primer itself contains chromates so chemical analysis of the surface proved futile. A comparison of the exterior surface of the former with the primer removed vs. a golden yellow chromate conversion coated component is presented in figure 24. The typical exterior surface of the primed coating can be observed in figure 25. This figure also includes the crack prior to it being opened. The coating system can be observed in cross sections in figures 20 and 21. The primer measured ~0.001 in thick and was within the 0.0008–0.0012-in requirement. The chromate chemical conversion coating is usually just a dip process, and while it leaves a chemical signature, it cannot be observed in a cross section. The MIL-P-23377 coating was intact, relatively undamaged, and appeared uniform and consistent in application. The tailboom former mates with a larger section of a tailboom, and the cracks were within this compressed section forming a crevice. The primer was not marred or worn, just uniformly compressed from the assembly. The edge of this compression can be observed in figure 25. There appeared to be a band of corrosion pitting of various sizes and depths extending to ~0.150 in from the edge of the crevice formed by the assembly. This band can be observed in figure 26. Examples of the corrosion pits adjacent to the fracture are depicted in figures 27 and 28. The largest pit observed was estimated to be 0.004 inches deep and 0.005 inches in diameter. It is important to note that the pits in figure 27 were fully and completely painted over; the paint conformed to the pit surface topography. Therefore, the pits did not form under the paint; they existed immediately prior to the last painting. They either formed during service within the crevice or during overhaul processing. They were not found all about the exterior surfaces, so it is more likely that they formed within the crevice during service.

9. Failure Scenario

The tailboom former failed by a fatigue mechanism initiated at corrosion pits. These pits likely developed over time either from damage induced during overhaul or within the natural crevice formed by the tailboom former and its mating component in the assembly. Pits were observed both with paint covering them and inactive, and recently active and corroding. It is likely that some of the pitting corrosion was missed during overhaul and paint was reapplied over them.

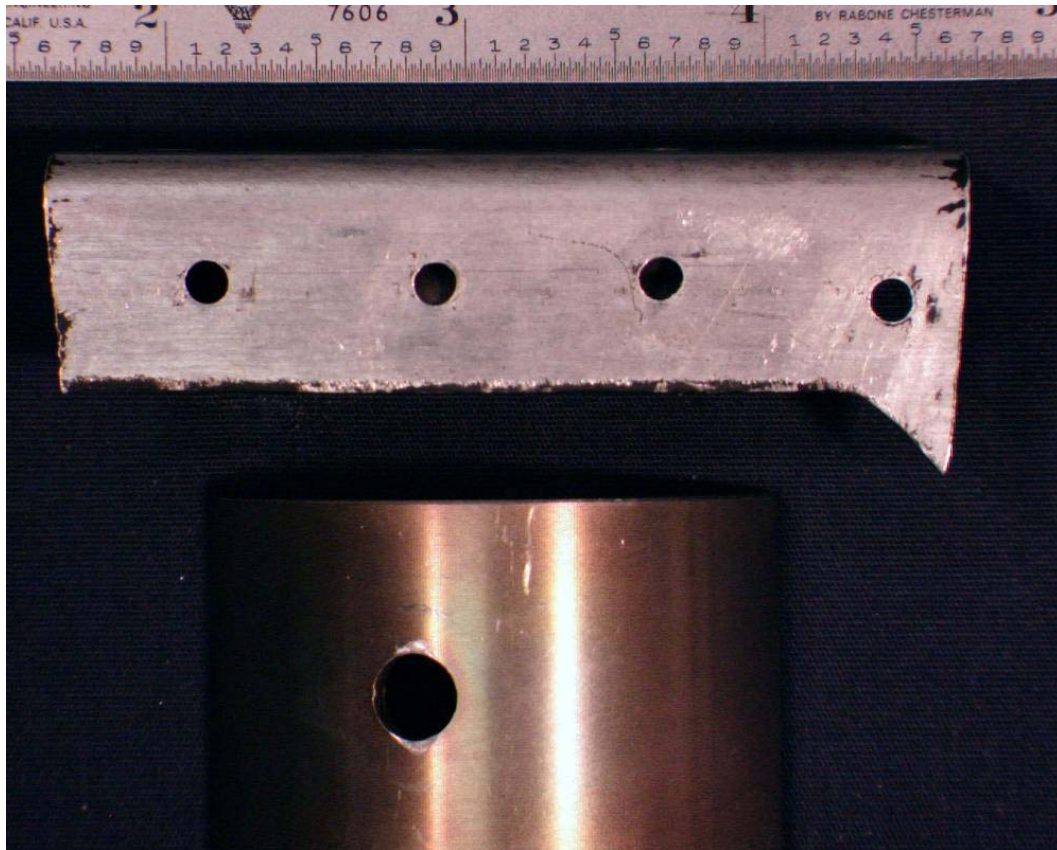


Figure 24. Former compared with a golden yellow chromate conversion coated component.



Figure 25. Exterior surface of the tailboom former coated with MIL-P-23377.

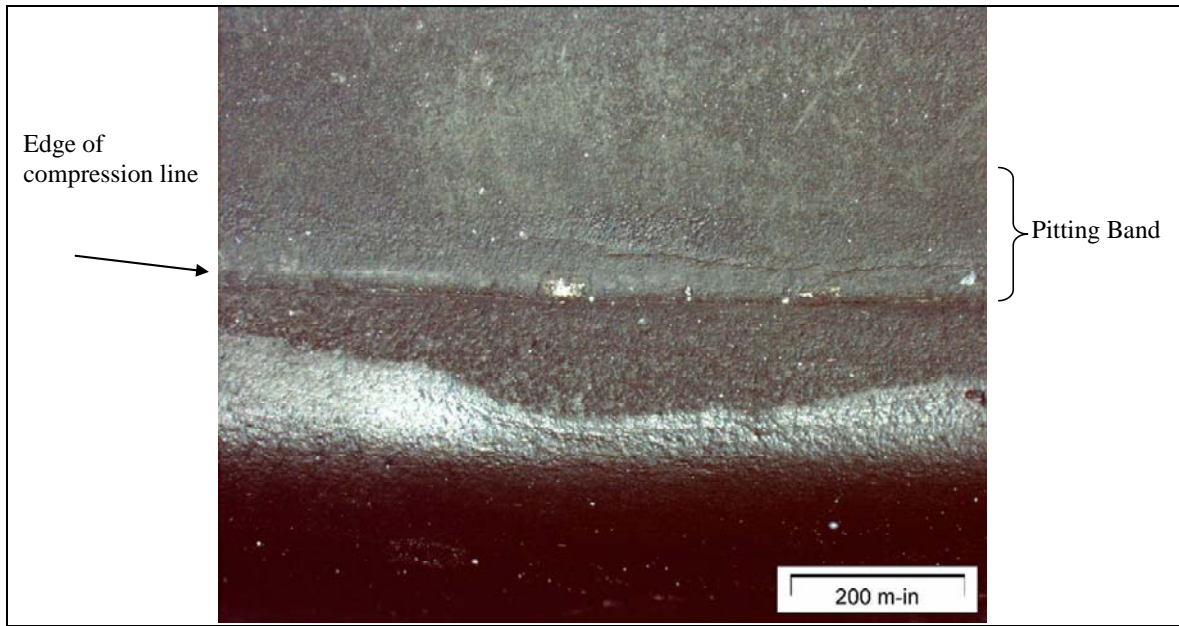


Figure 26. Corrosion pitting band near edge of crevice compression line.

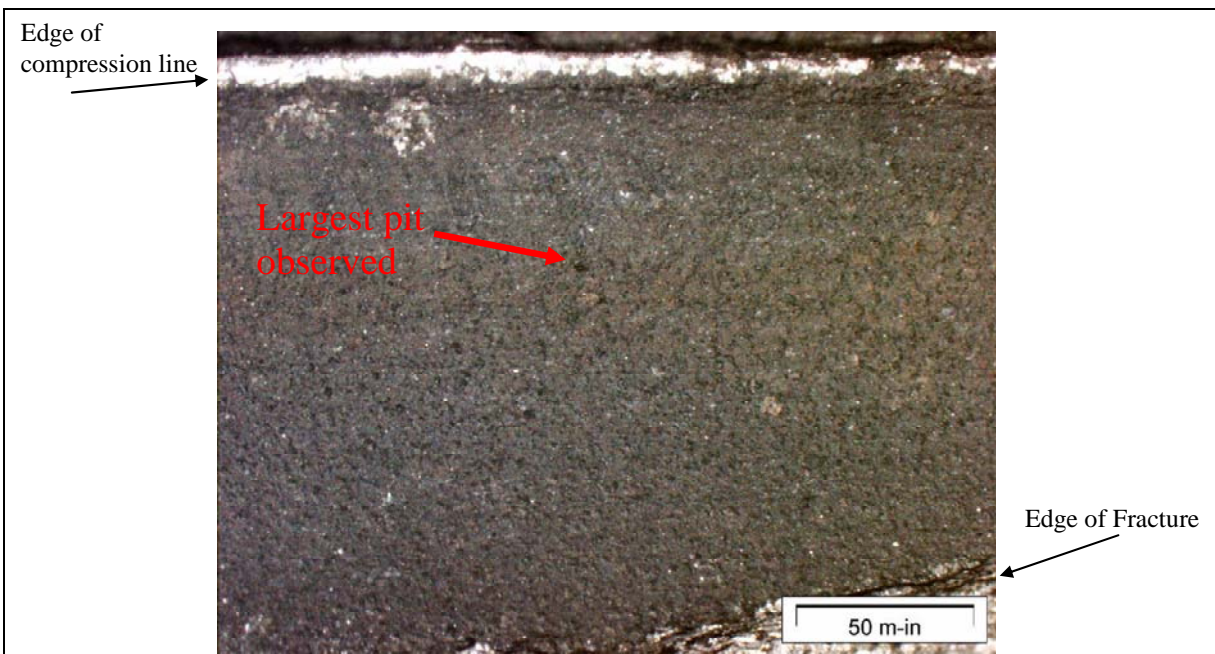


Figure 27. Pits adjacent to the edge of the fracture.



Figure 28. Pitting and corrosion product along the edge of compression line.

10. Conclusions

- The UH-1 tailboom former exhibited cracking near both of the bolt hole locations. The crack on side A (figure 1) was a through-thickness crack propagating entirely through the 0.050-in thickness of the component. The overall crack length was 1.25 in. The crack on side B was similar, and its overall crack length was 1.3 in.
- The cracks initiated and propagated by a fatigue mechanism at several corrosion pits located on the underside (or concave side) of the component. These shallow corrosion pits (0.005 in maximum) acted as stress concentration sites to initiate the cracking. The proximity of the bolt holes, ~0.75 in away, where the tailboom former would be held fast in the assembly, further contributed to the cracking in this area.
- The tailboom former appeared to be fabricated from a clad aluminum 2024-T4 alloy sheet. All chemical, physical, and mechanical testing performed was in agreement with this finding.
- No microstructural abnormalities were observed. The microstructure was consistent with clad aluminum 2024-T4 alloy sheet.

NO. OF
COPIES ORGANIZATION

1 DEFENSE TECHNICAL
(PDF INFORMATION CTR
ONLY) DTIC OCA
8725 JOHN J KINGMAN RD
STE 0944
FORT BELVOIR VA 22060-6218

1 US ARMY RSRCH DEV &
ENGRG CMD
SYSTEMS OF SYSTEMS
INTEGRATION
AMSRD SS T
6000 6TH ST STE 100
FORT BELVOIR VA 22060-5608

1 INST FOR ADVNCD TCHNLGY
THE UNIV OF TEXAS
AT AUSTIN
3925 W BRAKER LN
AUSTIN TX 78759-5316

1 DIRECTOR
US ARMY RESEARCH LAB
IMNE ALC IMS
2800 POWDER MILL RD
ADELPHI MD 20783-1197

3 DIRECTOR
US ARMY RESEARCH LAB
AMSRD ARL CI OK TL
2800 POWDER MILL RD
ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

1 DIR USARL
AMSRD ARL CI OK TP (BLDG 4600)

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND

10 USARL
 AMSRD ARL WM MC
 S GREND AHL

INTENTIONALLY LEFT BLANK.